UNIVERSITEIT GENT

FACULTY OF ENGINEERING

Experimental investigation of a Rotating Fluidized Bed in a Static Geometry

2nd European Process Intensification Conference
14-17 June 2009
Venice, Italy

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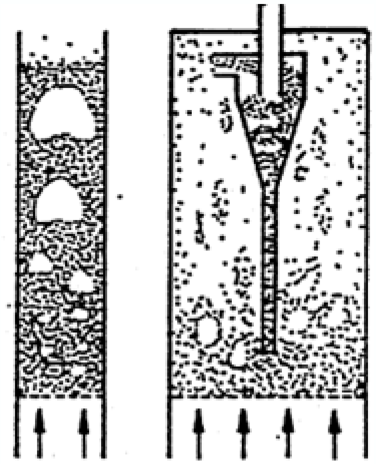
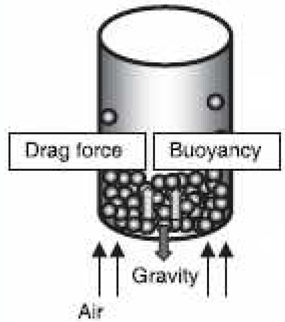
Outline

- Introduction
- Concept of Rotating Fluidized Bed in a Static Geometry (RFB-SG)
- Experimental set-up and its operation
- Results and discussion
  - Overall pressure drop
  - Maximum solid particles capacity
  - Solid particles velocity
  - Void fraction
- Conclusions

Introduction

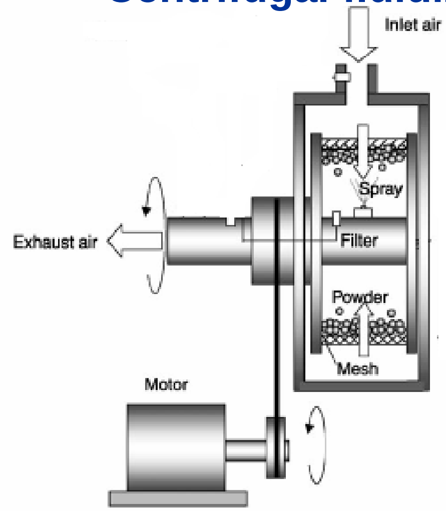
Gravitational fluidized bed reactors

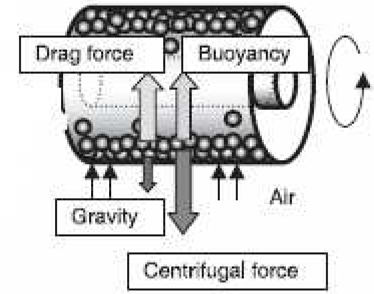




Drag force ~ Gravitational force

Centrifugal fluidized bed reactors





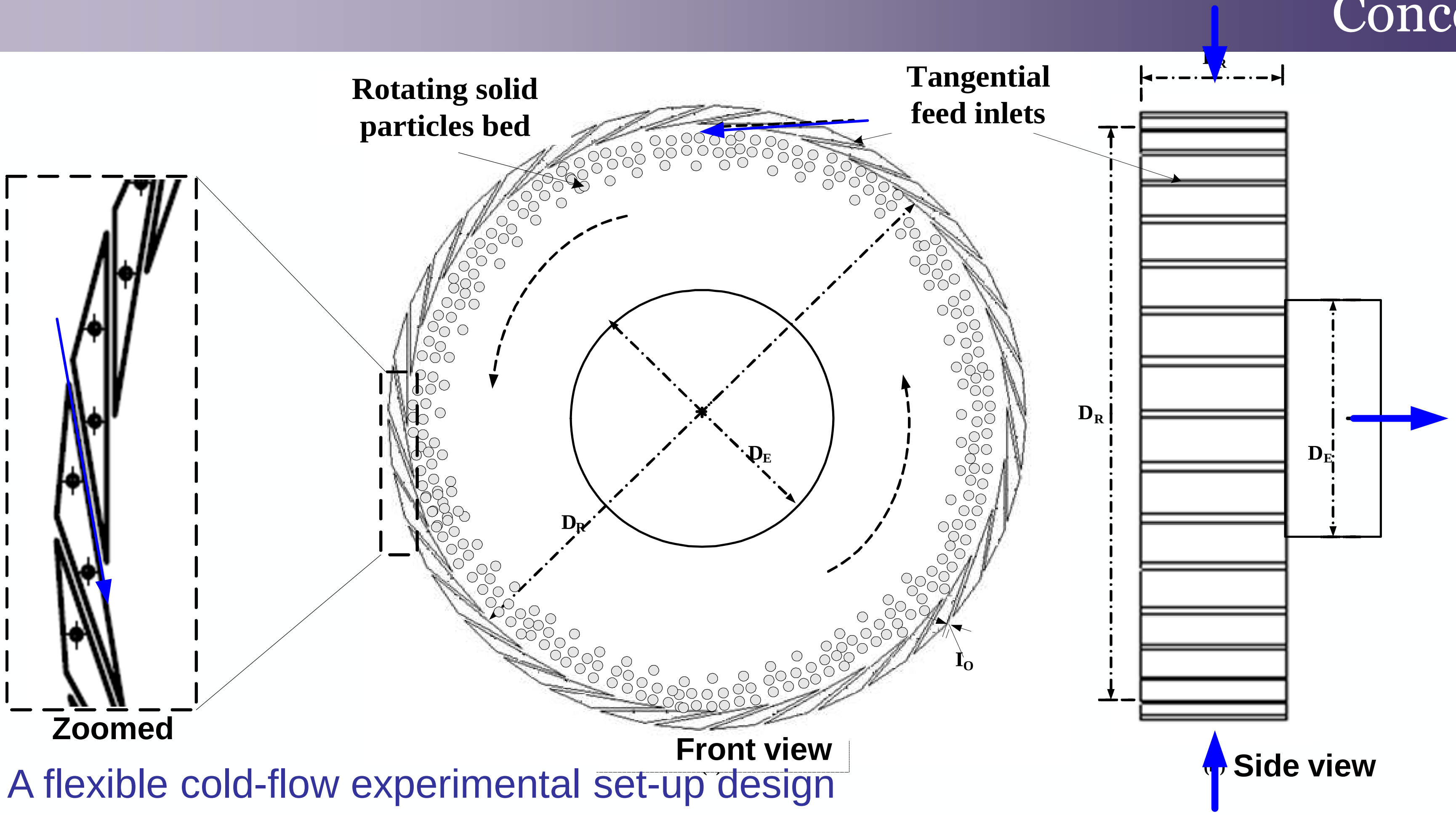
Drag force ~ Centrifugal force

Advantages of centrifugal fluidization in gas-solid operations

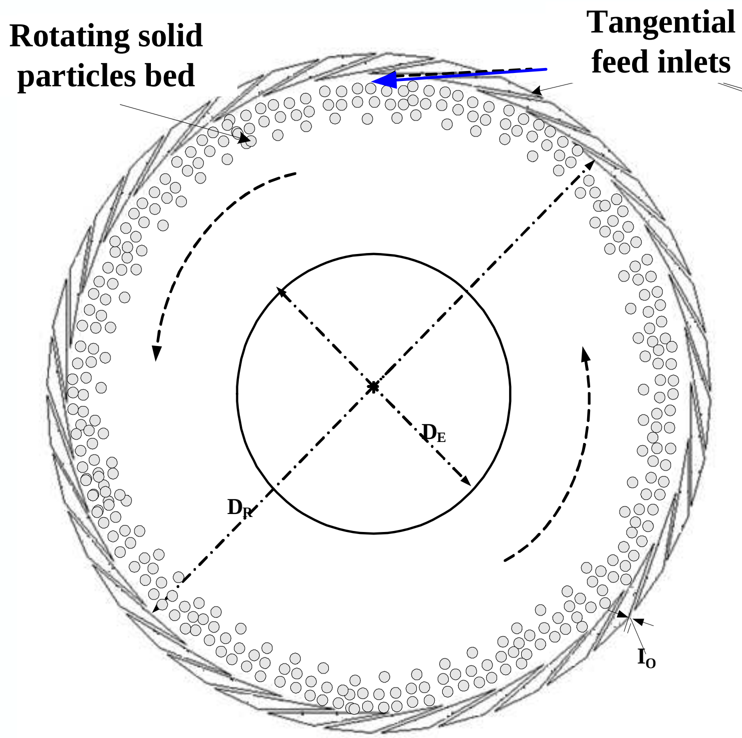
- Higher slip velocity, therefore, *high heat and mass transfer* at the particle scale
- *Uniform temperature* distribution at the reactor scale
- Ability to work at *high feed flow* rates

General applications of centrifugal reactors

- For short gas-solid contact time operations
- Drying, polymerization, fluidization of nano-particles, agglomeration, gas-solid separation, dust emission control



- A flexible cold-flow experimental set-up design
- Variation in:
    - Feed inlet opening thickness (I_O)
    - Number of feed inlets (n)
    - Reactor diameter (D_R)
    - Exhaust diameter (D_E)
    - Mode of operation – Pressure or Suction
    - Axis of rotation – Horizontal or Vertical

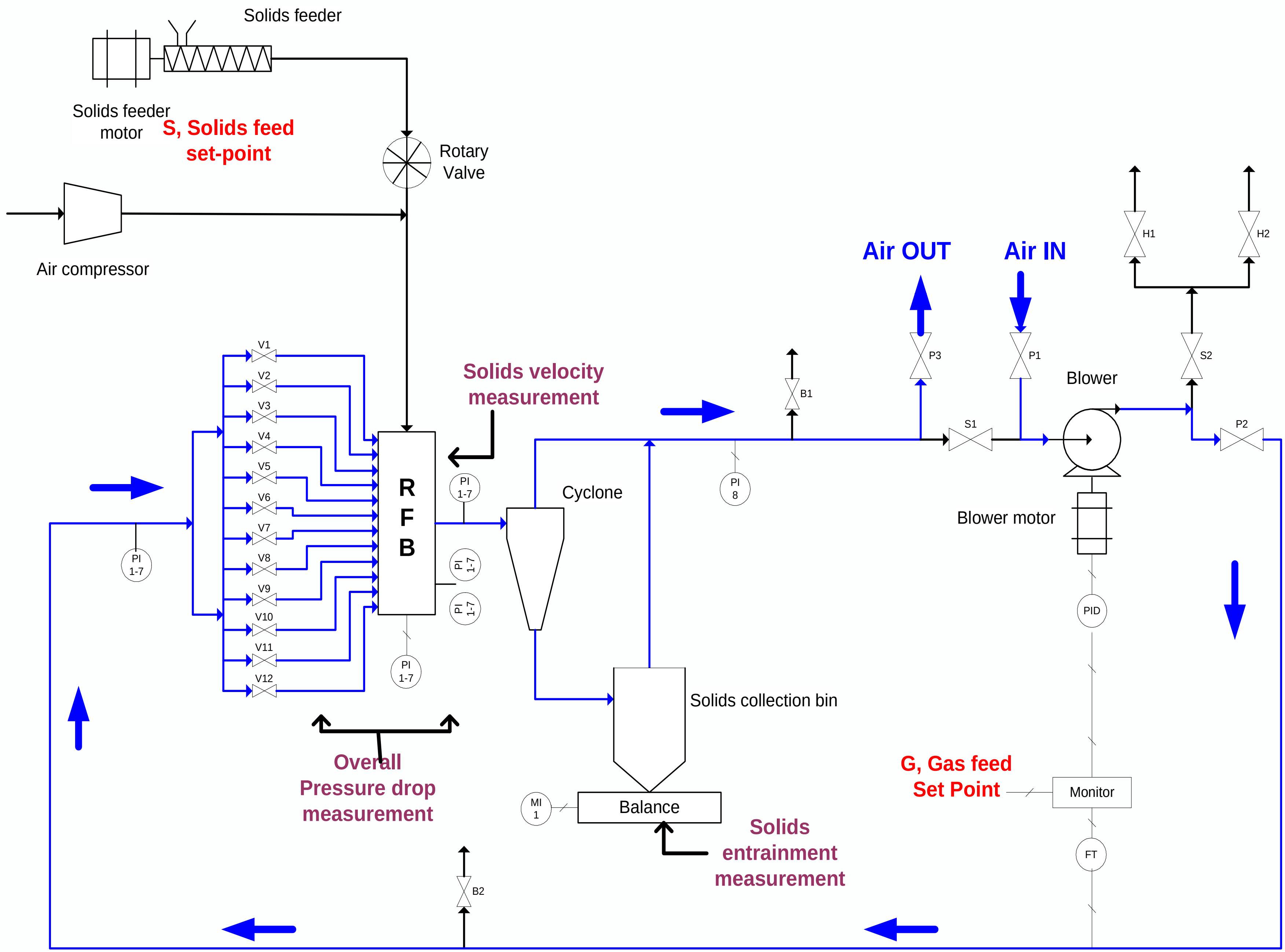


Front view

Snapshot of stable rotating bed

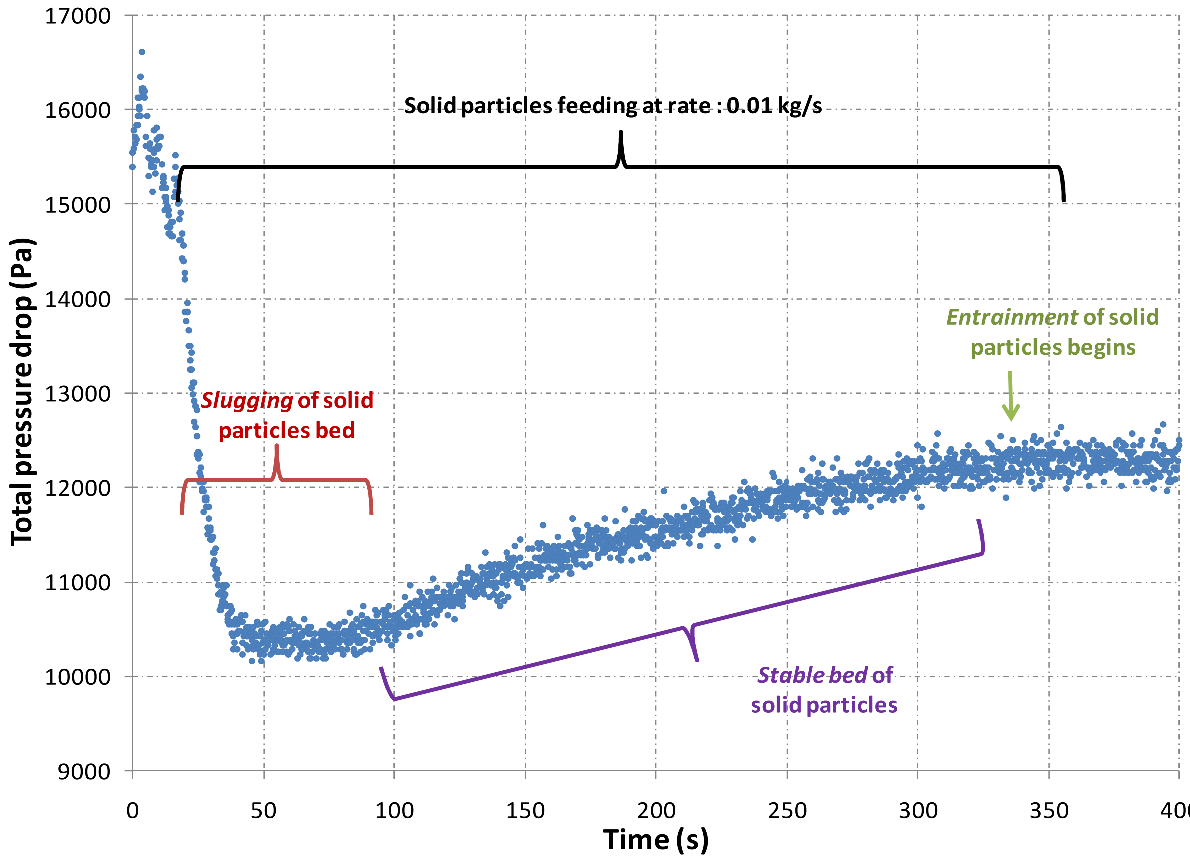
- Variation in:
  - Gas flow rate
  - Solids feed rate
  - Solids content
  - Solid particles size
  - Solid particles density

- Goal is to obtain a stable axisymmetric rotating bed of solid particles


Solids feeder
Solids feeder motor
S, Solids feed set-point
Rotary Valve
Air compressor
Air OUT
Air IN
H1
H2
P3
P1
S2
B1
Blower
Solids velocity measurement
S1
P2
V1
V2
V3
V4
V5
V6
V7
V8
V9
V10
V11
V12
R F B
PI 1-7
PI 8
Cyclone
Blower motor
PID
Solids collection bin
Overall Pressure drop measurement
G, Gas feed Set Point
Monitor
MI 1
Balance
Solids entrainment measurement
FT
B2

Typical operation & conditions

Independent geometrical variables	Value
Reactor diameter	0.54 m
Feed inlet opening thickness	0.002 m
Number of inlets	36 (-)
Mode of operation	Pressure
Axis of rotation	Horizontal



Independent operating variables	Range
Air flow rate	0.4 kg/s to 1.2 kg/s
Solid particles size	0.9 mm to 3 mm
Solid particles density	950 kg/m^3
Solids content	0.5 kg to 6 kg

Dependent variables	Measurement technique
Pressure drop	Pressure probe and sensors
Solid content	Real time weighing balance
Solid particles bed height	High speed camera
Solid particle velocity	High speed camera

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  - Solid particles velocity

  - Void fraction
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Total pressure drop behavior

- Contributions in the *total pressure drop*

$$\Delta P_{total} = \Delta P_{packed\ bed\,(radial)} + \Delta P_{\tan gential} + \Delta P_{inlet\ slots} + \Delta P_{Free-board}$$

Theoretical calculation (Ergun equation)

Experimentally measured

- *Ergun equation* for packed bed pressure drop (Radial pressure drop)

$$\Delta P_{packed\ bed} = \phi_1 U_0 r_0 \ln\left(\frac{r_0}{r_i}\right) + \phi_2 U_0^2 r_0^2 \left(\frac{1}{r_i} - \frac{1}{r_0}\right)$$

where,

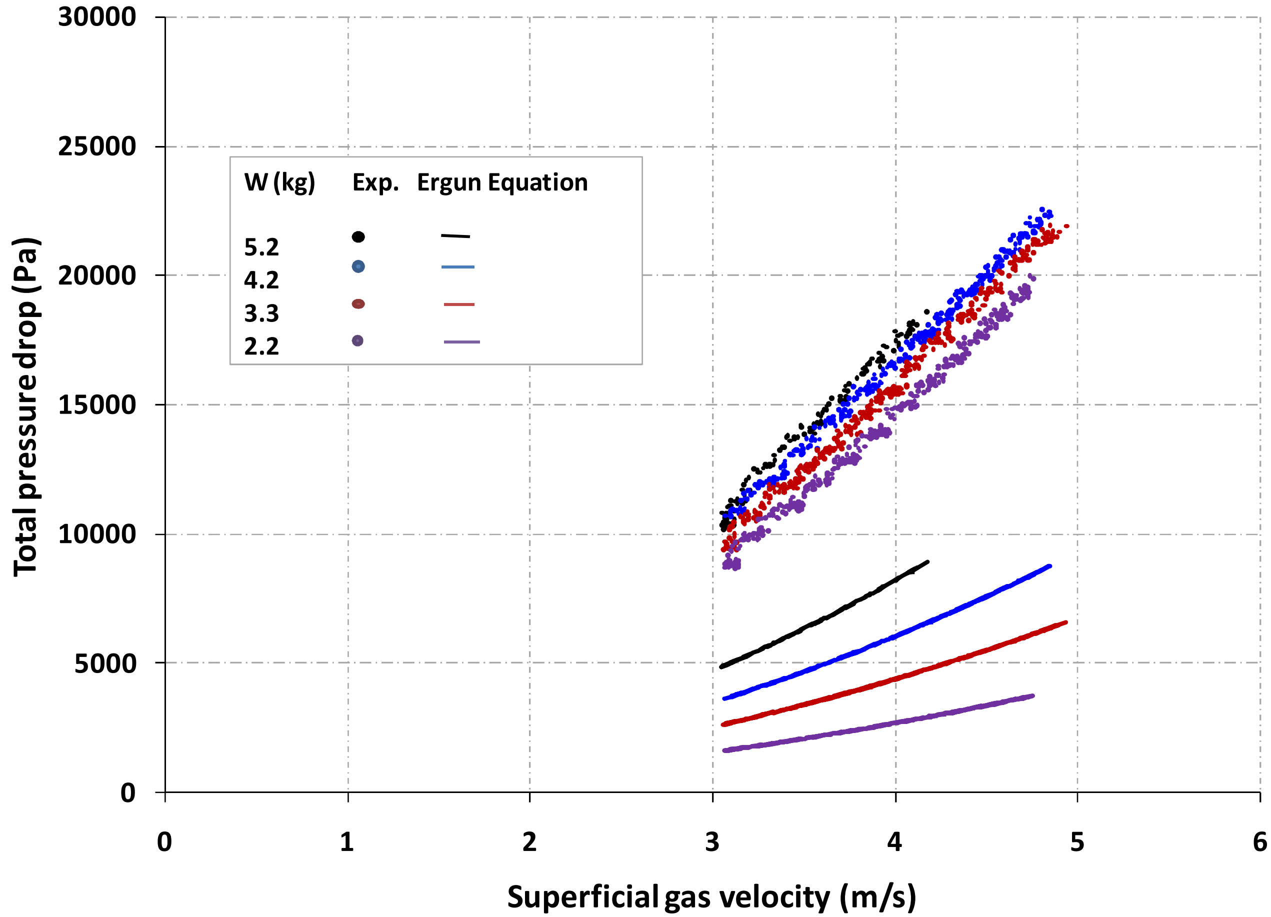
$$\phi_1 = \frac{1650(1-\varepsilon)\mu}{d_p^2}, \qquad \phi_2 = \frac{24.5(1-\varepsilon)\rho_g}{d_p},$$

$$U_0 = \frac{G}{\pi D_R L_R}$$

Notations:

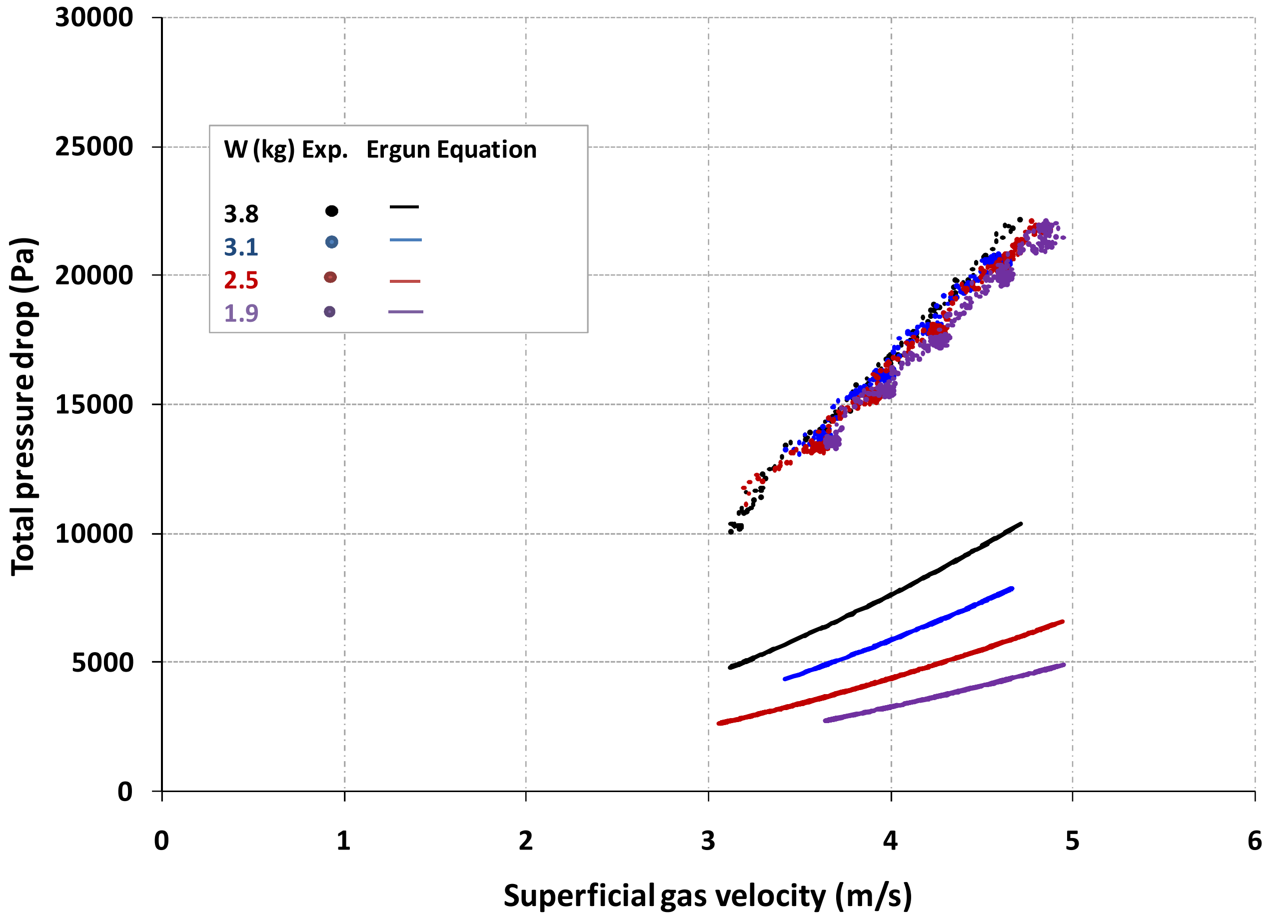
d_p	Mean particle diameter (m)
D_R	Diameter of the reactor (m)
L_R	Axial length of the reactor (m)
G	Volumetric gas flow rate (m^3/s)
r_0	Outer radius of packed bed (m)
r_i	Inner radius of packed bed (m)
U_0	Superficial gas velocity (m/s)
ΔP	Pressure drop (Pa)
ε	Void fraction (-)
ρ_g	Density of gas (kg/m^3)
μ	Gas viscosity (kg/ms)

Overall pressure drop behavior



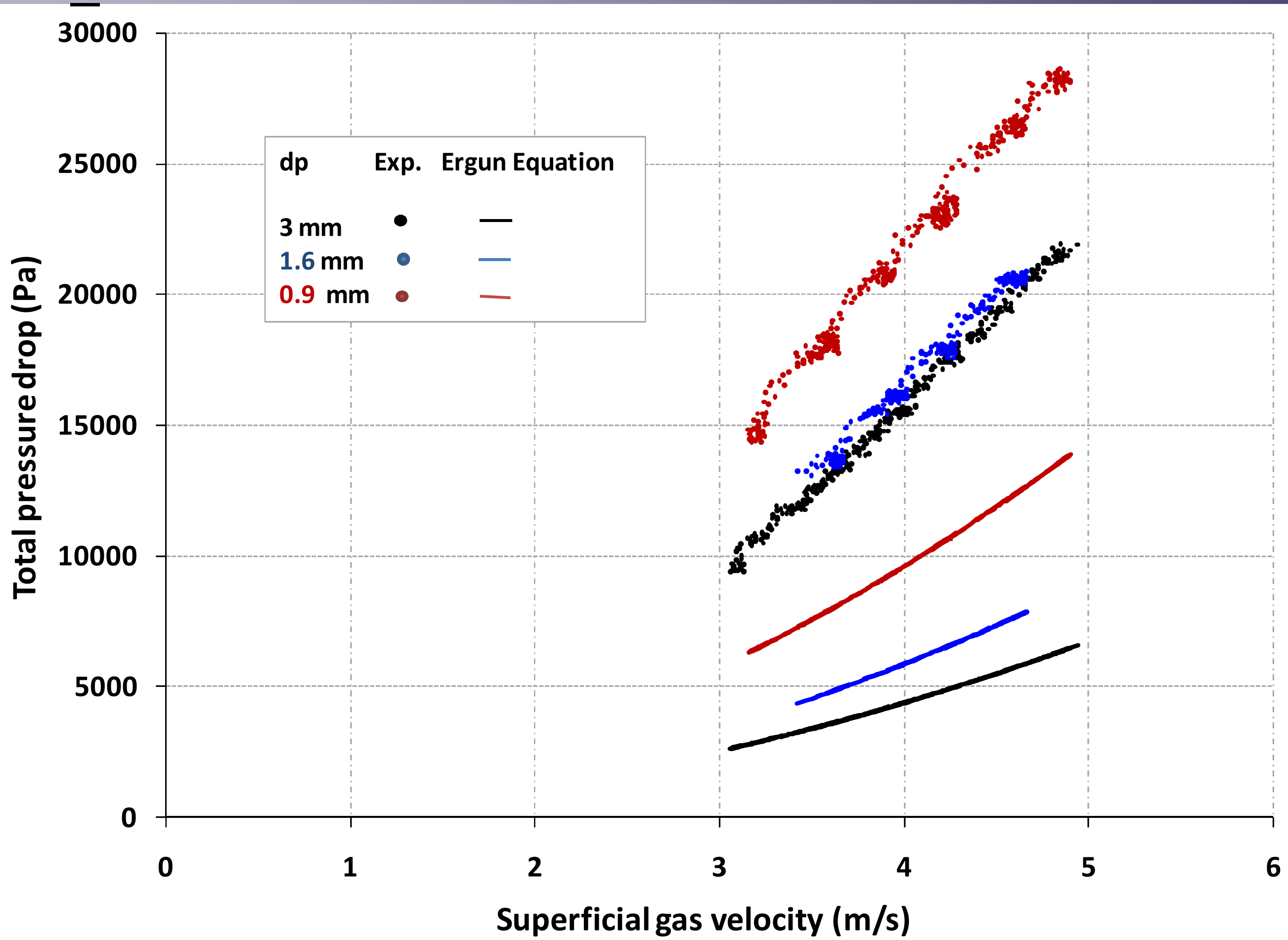
Total pressure drop v/s superficial gas velocity at various solids content for solid particles with size : 3 mm

- Pressure drop behavior is the *signature* of the flow in the reactor
- As the solids content increases, overall *bed height increases*, leading to an increased pressure drop



Total pressure drop v/s superficial gas velocity at various solids content for solid particles with size : 1.6 mm

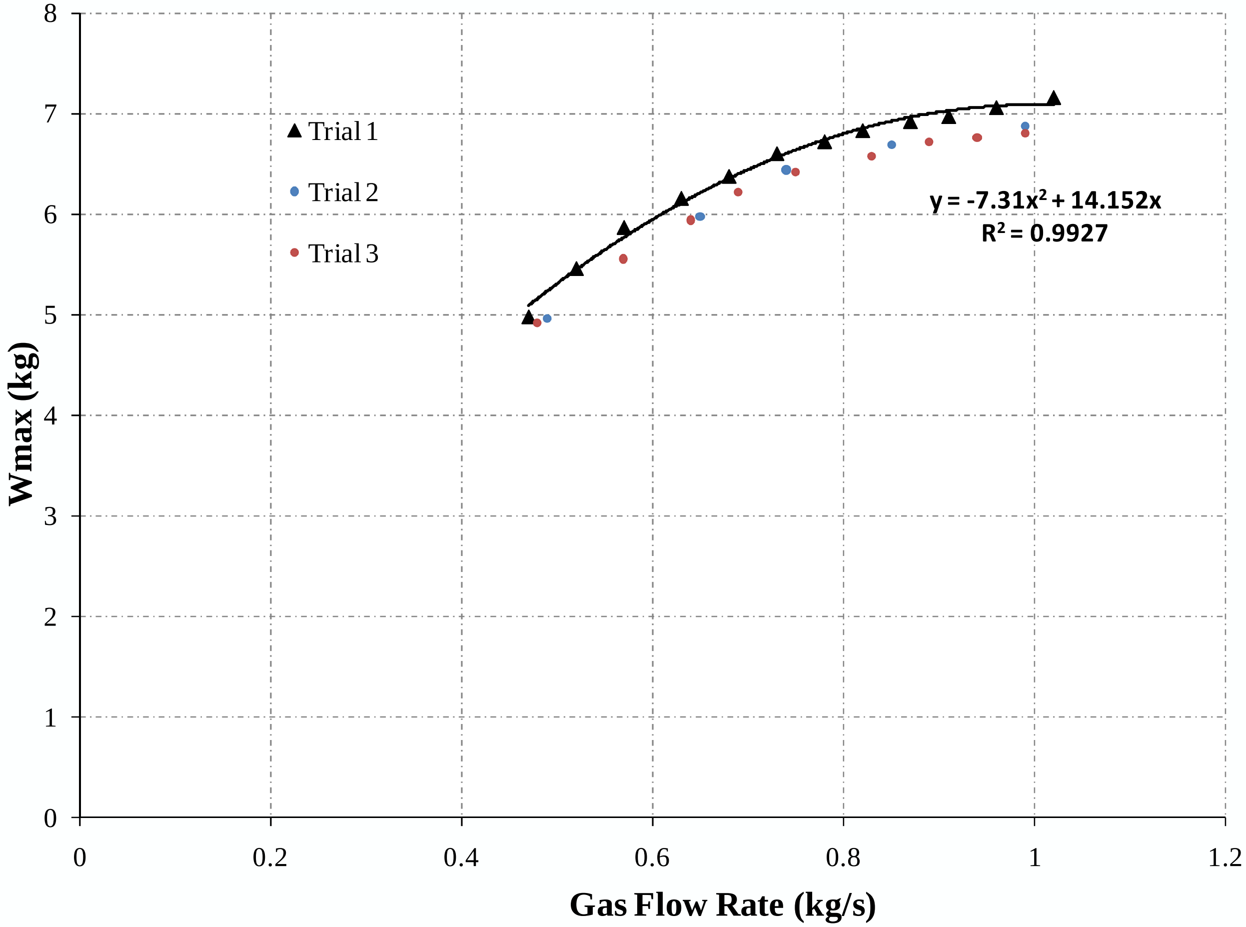
- *Similar* behavior of pressure increase observed for different particle size



Total pressure drop v/s superficial gas velocity at various solid particles size, and constant solids content of 3kg

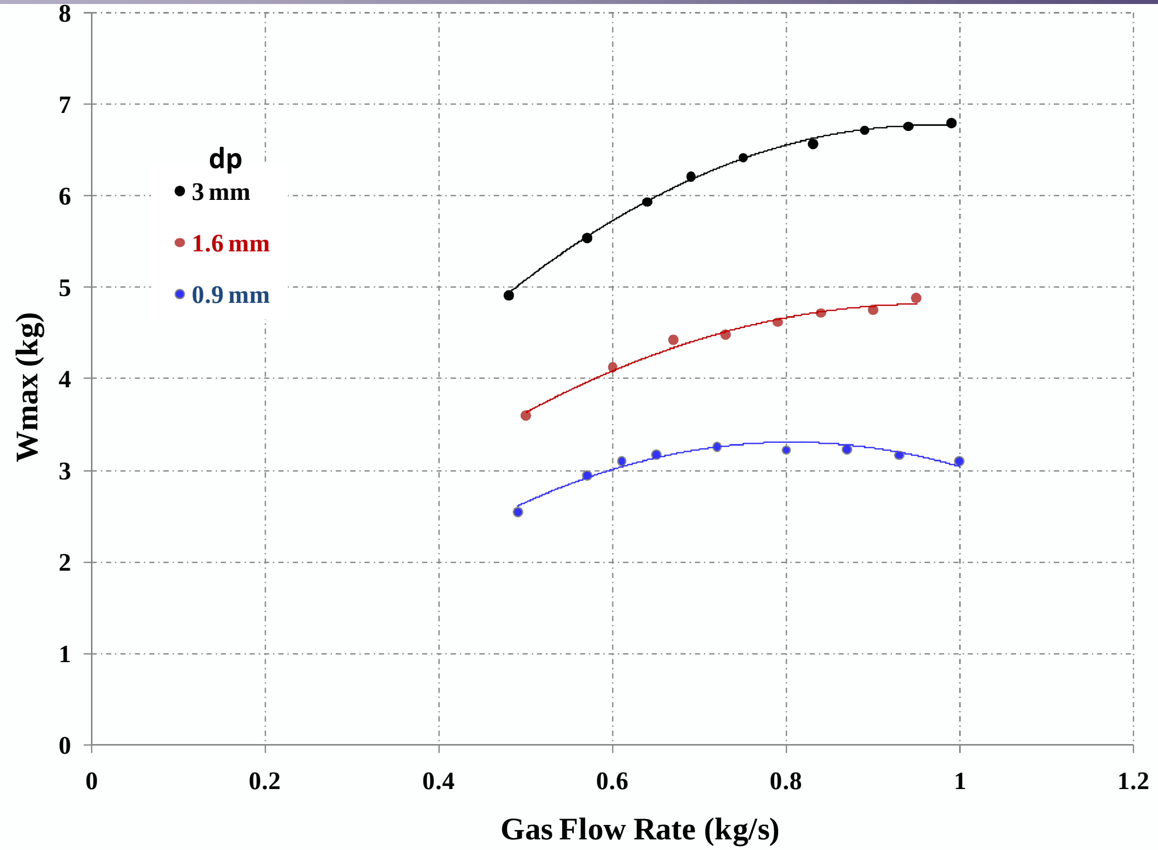
- Decrease is solid particle size, increases the *specific surface area*, this is leads to increase in *radial drag forces*, resulting into to higher pressure drop across the solid particles bed

Maximum solids content in the reactor



- Maximum solids content gives an idea about average solids residence time (for drying operations), and space velocity (WHSV)
- Increasing gas flow rate *increases* the maximum solids capacity of the reactor
- This is one of the *distinct feature* of RFB-SG compared to gravitational fluidized bed reactors

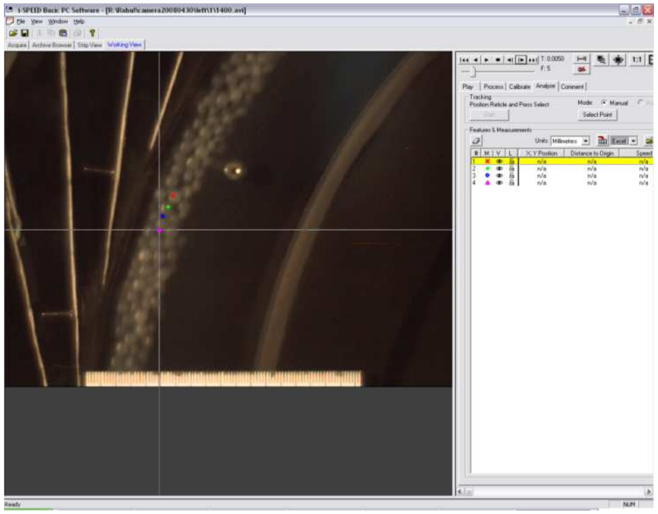
Maximum solids content in the reactor

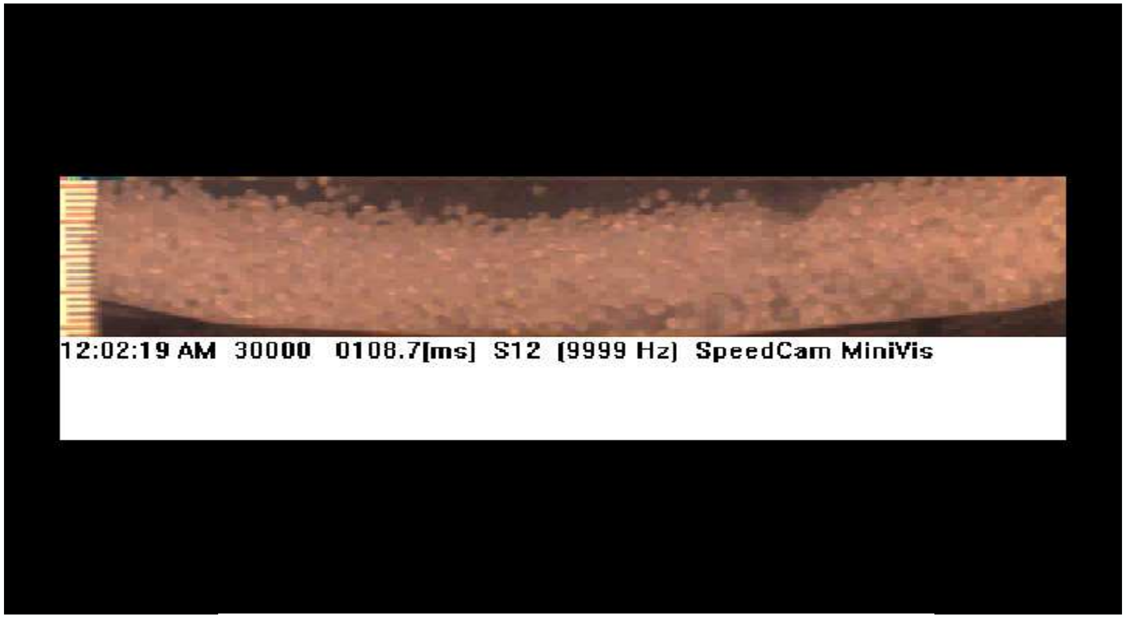


- At maximum solids content, centrifugal force is *balanced* by the gravity, resulting into *entrainment* of solid particles from the topmost position of the reactor exhaust
- Increasing gas flow rate, increases the centrifugal force, leading to increase in solids capacity until *equilibrium* with gravity is reached
- At lower particle size (~ 0.9 mm), *radial drag force* is dominant, resulting into early entrainment of solids from lateral positions of the reactor

Solid particles velocity measurement

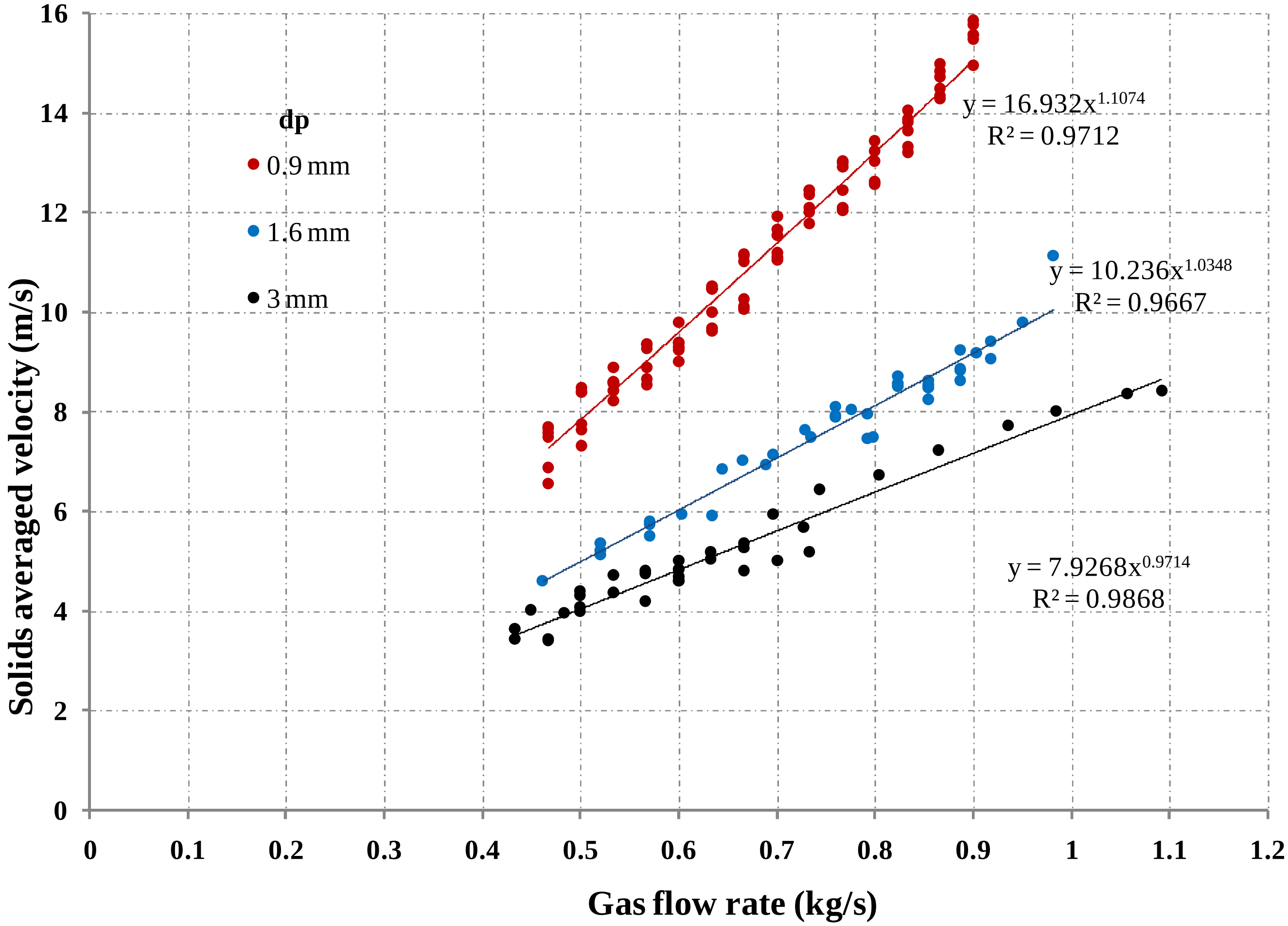
- Solids particle tracking by means of high-speed camera
- Measurement of solids velocity at several independent variables
- Image capturing at 3000 to 30000 frames per second
- Tracked particles further processed in x-y coordinate domain (only 2D measurements)





Solid particles flow captured by high-speed camera

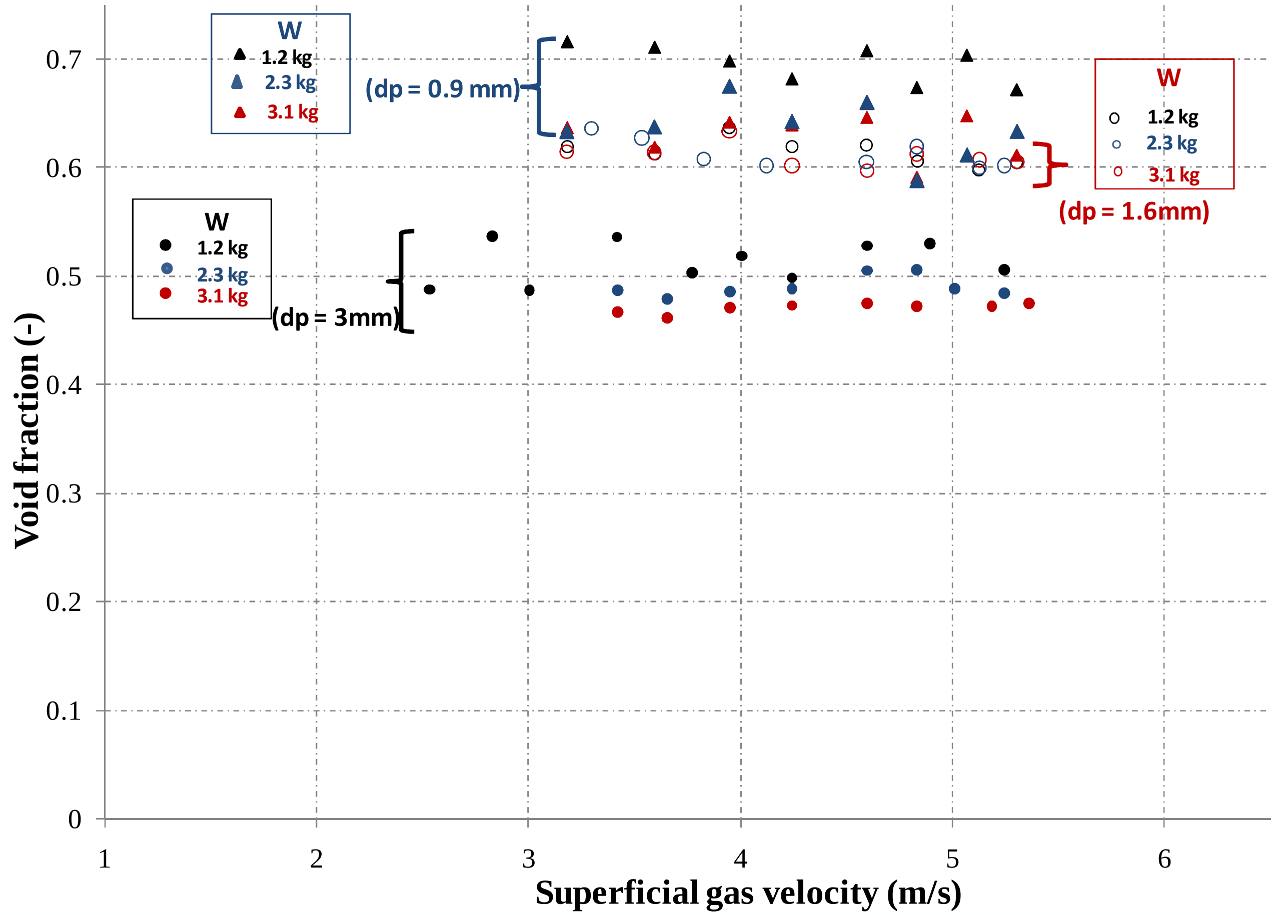
Solid particles velocity



- Decrease in particle size, results into *increase* in the solid particles velocity

- Increase in radial drag due to decrease in particle size is compensated by *higher centrifugal force*, and hence higher solid particles velocity

Void fraction



- Under investigated operating range, *negligible* change in void fraction is observed with varying gas flow rate

- This may be due to the constant *ratio* of centrifugal force to radial drag force, at given radial position, with varying gas flow rate

Conclusions

• A *flexible* experimental set-up was designed and built for the experimental investigation of the RFB-SG at *wide range* of operating conditions

• A *stable* solid particles bed was achieved under investigated operating range

• For given solid particles, total pressure drop increases with increasing *solids content*

• For given solids content, total pressure drop increases with decreasing *particle size*

• *Maximum solids capacity* increases with increasing gas flow rate for given solid particles

• *Solids velocity* shows linear dependence on gas flow rate

• Solids *volume fraction* remains almost constant for given solids content, with varying gas flow rate